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# Series-parallel Resonant High Frequency Inverter for Stand-alone Hybrid PV/Wind Power System

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**Abstract**

The objective of this paper is to propose a series-parallel resonant high frequency inverter for stand-alone hybrid photovoltaic (PV)/wind power system in order to simplify the power system and reduce the cost. The proposed inverter consists of two power stages: a DC/DC resonant converter as the input stage and a full bridge DC/AC inverter as the output stage. The input converter is operated with phase shift control, which guarantees zero current switching for most power range. This resonant converter generates a high DC voltage, which is conditioned by the DC/AC inverter to generate the desired low frequency output voltage. The DC/AC inverter is controlled using a pulse width modulation strategy. Simulation and experimental results are given to verify the system's efficiency and have shown the performance of the proposed inverter with desired features.



*Keywords: High frequency link inverter; hybrid PV/Wind Power; soft-switching; resonant*

## 1. Introduction

In the hybrid energy complementary power supply system (HECPSS), complementation embodies two aspects; one is conventional energy and renewable energy source have complementarities, and the other is wind energy and solar energy have very strong complementarities [1].

The PV/wind complementary power supply system is a reasonable power supply which makes good use of wind and solar energy. This system can provide a bargain of low cost and high dependability for some region where power transmission is not convenient such as frontier defenses and island, relay stations of communication, workstation of reconnaissance and survey and so on. Today, renewable energy can resolve crisis of conventional energy shortage and environmental pollution in the world, so the HECPSS has a bright application and development prospect [2].

Because wind energy and solar energy have traits such as randomness and uncertainty, it is very

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difficult to make use of the solar and wind energy all-weather just through wind-solar system. According to the local environment and the load characteristic, the rational capacity allocation of wind turbine generator, solar cells, diesel engine and storage battery can raise the security, reliability and continuity of power supply system, and reduces the system cost. A substantial energy storage battery bank is used to deliver the reliable power and to draw the maximum power from the PV arrays or the wind turbine for either one of them has an intermittent nature and the diesel engine is auxiliary [3]. The concrete composing of the system is seen in the Fig. 1.

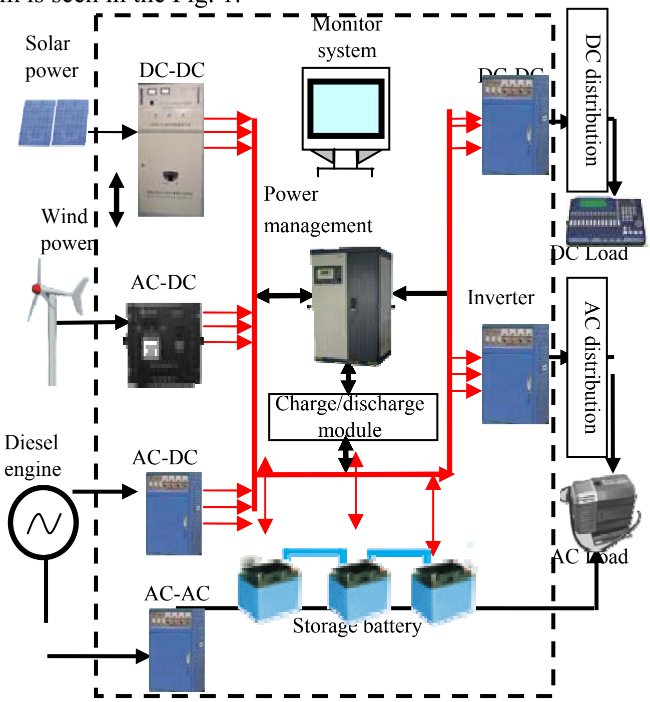


Fig. 1. Schematic diagram of the hybrid energy complementary power supply system

HECPSS used in the fixation spot is a typical independence and finite capacitance system, whose operation parameter such as voltage, current and load angle must be maintained in the ideal state, so supervisory control and management of HECPSS with many equipments and variables is complex. In addition, for supplying AC loads in a PV power system, an inverter is a critical component, which converts the DC power of the module and the battery into AC, generally in the form of 50 Hz power [4].

The objective of this paper is to propose a novel converter for stand-alone hybrid PV/wind power system. The converters are usually designed to produce high quality, low distortion AC power. The proposed inverter has the following advantages: (1) the application of high frequency link transformer in the sine inverter power supply is given. To use the high frequency link transformer instead of silicon-steel transformer which is traditionally and widely used, the higher power-density and reliability are achieved. (2) The resonant technique is include in order to eliminating the EMI due to power conversion ,and the power supply's efficiency is improved though the resonant technique. (3) The circuit topology is simple and as for phase-shift controlled circuit, the switches operate in soft-switching condition, therefore, the switching loss of the whole circuit is lower.

## 2. Operation Principle of the Proposed Converter

The block diagram of the proposed high frequency link inverter is shown in Fig.2. It consists of a two power stage: a series resonant inverter with constant frequency phase shifted control and high frequency transformer is input stage, the series resonant full-bridge inverter circuit with phase-shifted control guarantees zero voltage switch for the behind circuit, the high frequency transformers is used for isolation and transforming voltage. The second stage consists of full bridge rectifier circuit with high frequency and fast recovery diode, low pass filter and single phase full-bridge inverter.

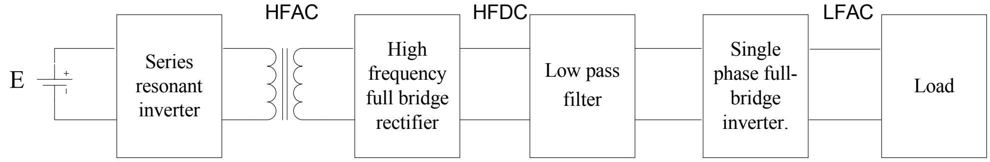


Fig. 2. Block diagram of the high frequency link inverterSeries resonant inverter

The total losses associated with such operations may impact the efficiency, size and total cost of the overall design. One solution for such hardship is the use of resonant converters in which the stresses and losses upon the electronic devices can be minimized by controlling the switching times that occur at the instants when the current through and/or voltage across the converter switches become zero. This technology is known as soft-switching. In addition to the zero voltage/current switching conditions (ZVS/ZCS), this approach has other advantages, such as: elimination of snubber losses, improvement of device reliability, less *dv/dt* stress on magnetic device insulation, reduced EMI problems, reduction of machine aging due to stresses and voltage boost effect at machine terminals with long cables [5].

It is possible to use load resonant converters to create high frequency AC (HFAC) link, allowing the connection of different loads on a common bus. In this paper, a LCC load series resonant converter is presented in Fig. 3, which have the advantage of both the LC load series and the load parallel connection resonance converter, and it have better property of output voltage [6].

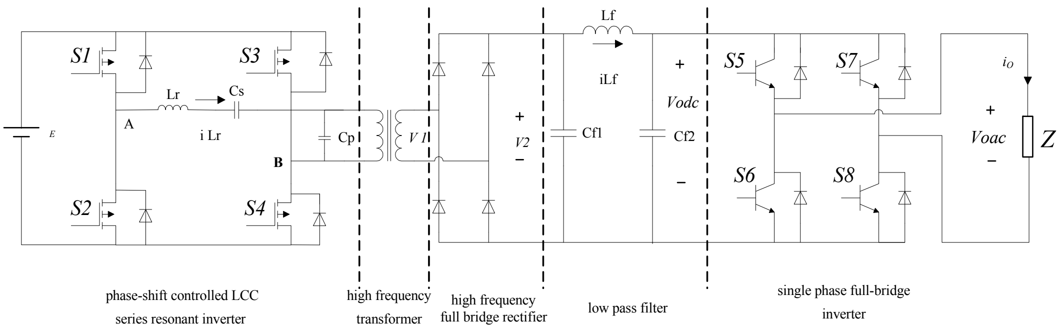


Fig. 3. Phase-shifted HF link inverter on the basis of LCC resonant circuit

As shown in Fig.3 the primary circuit constitutes LCC series resonant full bridge converter that controlled by phase-shift and SPWM, S1 and S2 are a leading arm, S3 and S4 are a lagging arm. The angle $\theta$ between drive signals of S1 and S4 is defined as phase-shifted angle. The output voltage $V_{AB}$ can be regulated through regulating phase shift angle θ [7]. Switches S1-S4 are operated in an alternating way, to produce a high frequency voltage on the transformer terminals, and the power balance on the resonant circuit is assured. The resonant tank is composed of the capacitor $C_r$, $C_p$ and of the inductor $L_r$. The transformer leakage inductance can be added up to obtain the desired resonant inductance. The zero-voltage interval occurs between point A and B, so its leading arm turns on at ZVS, and lagging arm turns off at ZCS, two zero-voltage intervals in one period are obtained.

*2.1. High frequency full bridge rectifier and filter circuit*

Intermediate high frequency full bridge rectifier forms by the high frequency fast recovery diode, it will convert the transformer export pulse voltage of high frequency to sine half wave pulse voltage, and pass from low pass filter which be composed by capacitor $C_{f1}$, $C_{f2}$ and inductance $L_f$ to exclude its carrier wave of high frequency, leave the alternating signal of low frequency. As shown in Fig.4.

*2.2. Low frequency single phase inverter circuit*

The output stage is single phase inverter, its switch turn on and off at the time when the low frequency sine voltage $V_{odc}$ is zero. So the inverter turns on at ZVS. The output voltage $V_{oac}$ is obtained by the SPWM controller. And its frequency is low.

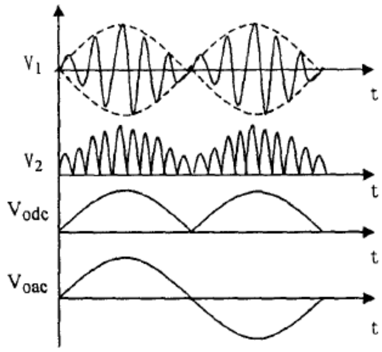


Fig. 4. Waveforms of working principle

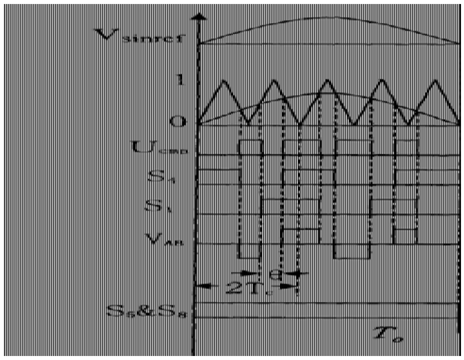


Fig. 5. Waveforms of control method

**3. Principle of Control Circuit**

The control principle of the switch $S_1$-$S_4$ in primary phase shift controlled circuit wave is show in Fig.5, in which, $U_c$ is a triangle wave signal as signal carrier. its carrier frequency $f_c=1/T_c$ .$U_m$ is sine half wave modulation signal, its frequency the two times in correspondence with sine wave output voltage frequency $f_m=2f_o=2/T_o$.

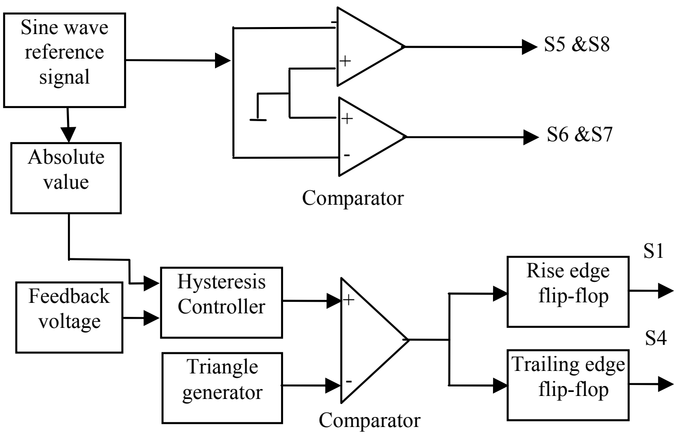


Fig. 6. Block diagram of the controller circuit

Its basic working process: Triangle wave signal and modulation signal carry out only unipolarity modulation, form sine pulse wide modulation signal $U_{cmp}$. Its principle is when triangle wave signal is higher than modulation signal, outputs low level; when triangle wave signal is lower than modulation signal, outputs high level [7].

Then sine pulse wide modulation signal $U_{cmp}$ dropping and rising edge is as the trigger signal of divide-by-two circuit, then can get the driving signal of switch $S_1$ and $S_4$. According to complementary relation, we can get the driving signal of switch $S_2$ and $S_3$. Through detecting zero-crossing of reference sine wave $U_{sinref}$, gets driving signal of switch $S_5$-$S_8$ [8].

Under the condition of $0.1<m<0.5$, the phase shifted angle θ is controlled in term of sine law which makes the magnitude of resonant voltage track a reference sine voltage ,and the resonant voltage is rectified, filtered , inverted and then the better sine voltage output is obtained [9] .

## 4. Simulation Result

The following results are based on the converter structure and control described in the last section. The values used for all the elements are presented in Table 1.

Table 1. Circuit value

| $E$ | $C_p$ | $C_s$ | $L_r$ | $f_s$ |
|---|---|---|---|---|
| *220V* | *0.28uF* | *0.6uF* | *58uH* | *20KHz* |
| $C_{f1}$ | $C_{f2}$ | $L_f$ | $K$ | $m$ |
| *0.1uF* | *0.1uF* | *5mH* | *2* | *0.5* |

Fig.7 shows the waveforms of phase shift control. Fig.7 a and b verifies that the switches in the leading arm turn on at ZVS. Fig.7 c and d proves that the switches of the lagging arm turn off at ZCS.

Fig.8 proves that the switches of the output stage turn on and off at ZVS.

Fig. 9 presents the output voltage and load current for sudden load change. It can be seen that the converter is supplying rated load up to 0.04 seconds of simulation, when a 50% rated load is applied, and output voltage is almost not affected.

## 5. Conclusions

The control method of phase-shift controlled HF link inverter for is proposed. The following conclusions are drawn by theoretical analysis and simulation results. The circuit topology is so simple that it is easy to realize synchronous control; zero-voltage intervals of output voltage of phase-shifted circuit are very stable. As for phase-shift controlled circuit, the switches in the leading arm turn on at ZVS, and there are no switching losses during the operation of zero-voltage vectors of the inverter, therefore, the switching loss of the whole circuit is lower. This series resonant high frequency inverter have a good output characteristic, it is good for stand-alone hybrid photovoltaic (PV)/wind power system , can be used in the fixation spot or residential appliances.

## Acknowledgements

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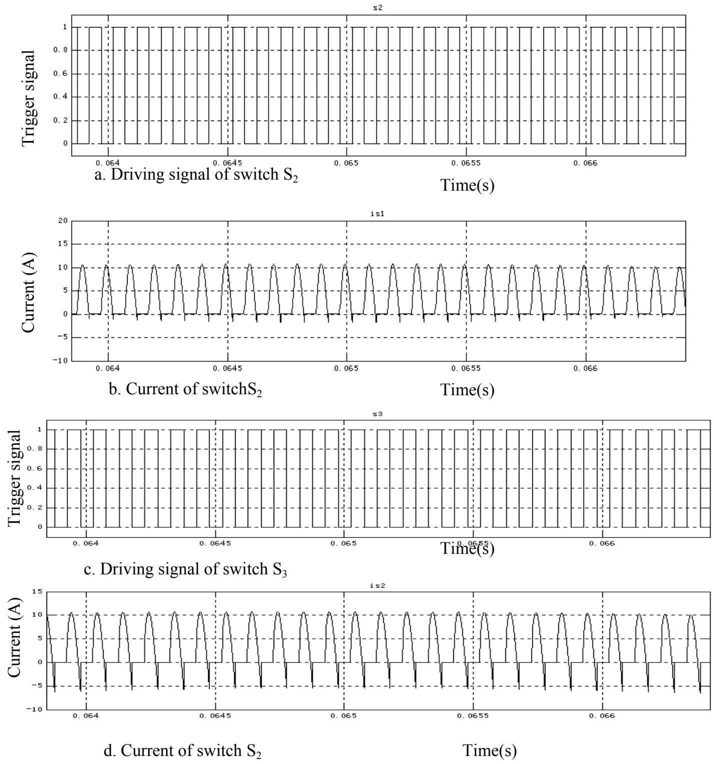


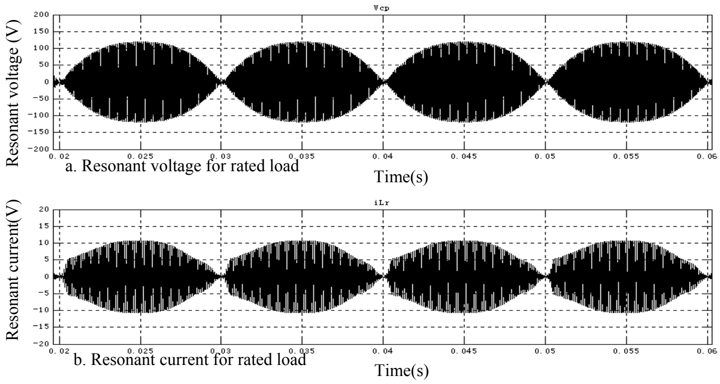

a. Driving signal of switch $S_2$

b. Current of switch$S_2$

c. Driving signal of switch $S_3$

d. Current of switch $S_2$

Fig. 7. Waveforms of phase shift control circuit




a. Resonant voltage for rated load

b. Resonant current for rated load

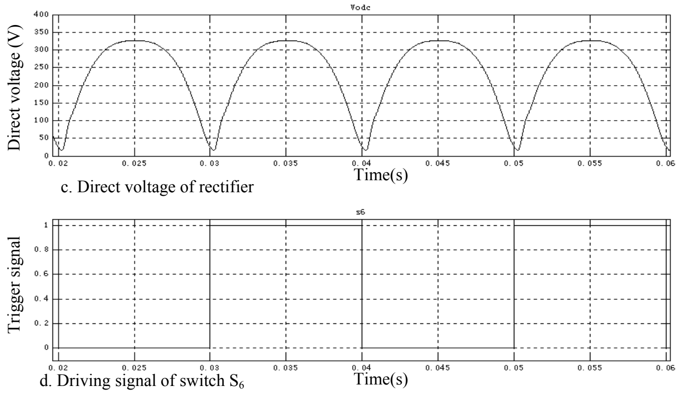



Fig. 8. The waveforms of the second stage circuit

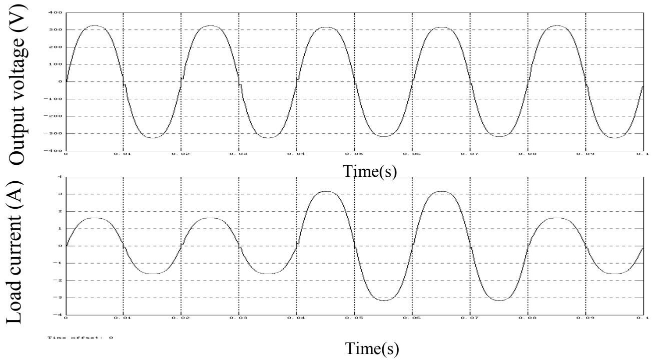



Fig. 9. Waveforms of output voltage and current for sudden change load

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